Flexible FlueCO_2

Luna Labs, Matthew Merrill

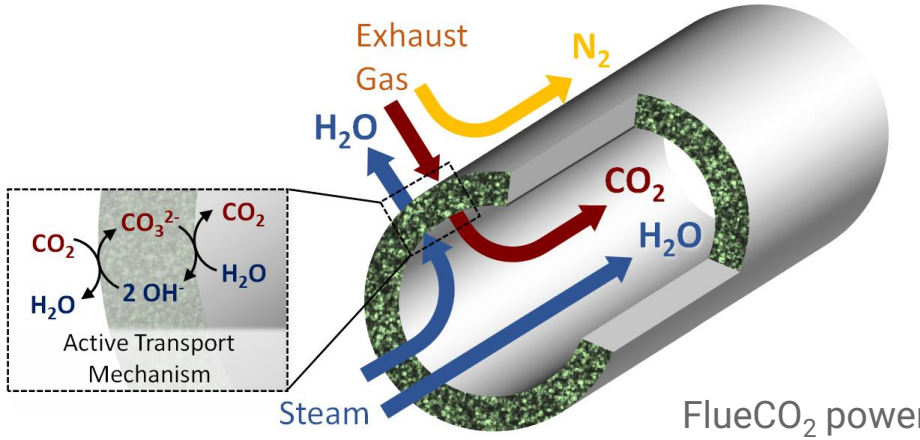
Nooter/Eriksen

Trimeric Corporation

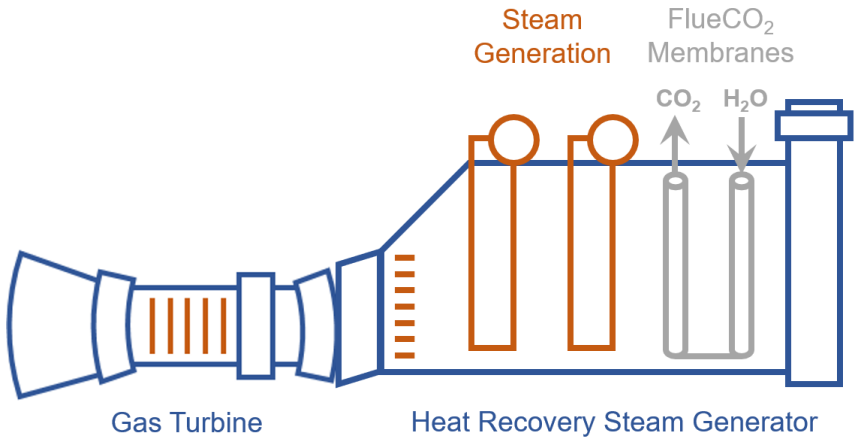
Luna's FlueCO_2 membranes enable cost-effective carbon capture with minimal impact on natural gas combined cycle power plant performance.

The FlueCO$_2$ Concept

- Unique dual phase membrane technology
- Integrates into the heat recovery steam generator (HRSG) of natural gas combined cycle (NGCC) power plants
  - The NGCC fleet is the highest impact market
- Power + CO_2 capture is profitable at low electricity prices (22 – 35 $/MWe)
  - Win by being the first plant turned on by dispatcher
- Capture CO_2 except in emergencies (>400 $/MWe)
  - Achieved with high energy efficiency



FlueCO$_2$ powers CO_2 separation with H_2O concentration gradients



Inorganic membranes operate within the HRSG at 150 – 350 °C

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The FlueCO$_2$ Team

Luna Labs: Contract Research & Tech Incubator focused on Product Development

Matt Merrill (PI)
Greg Simms
Jesse Kelly

- Membrane technology
- Plant concept
- Cost modeling

Nooter/Eriksen: world leading supplier of HRSG technology

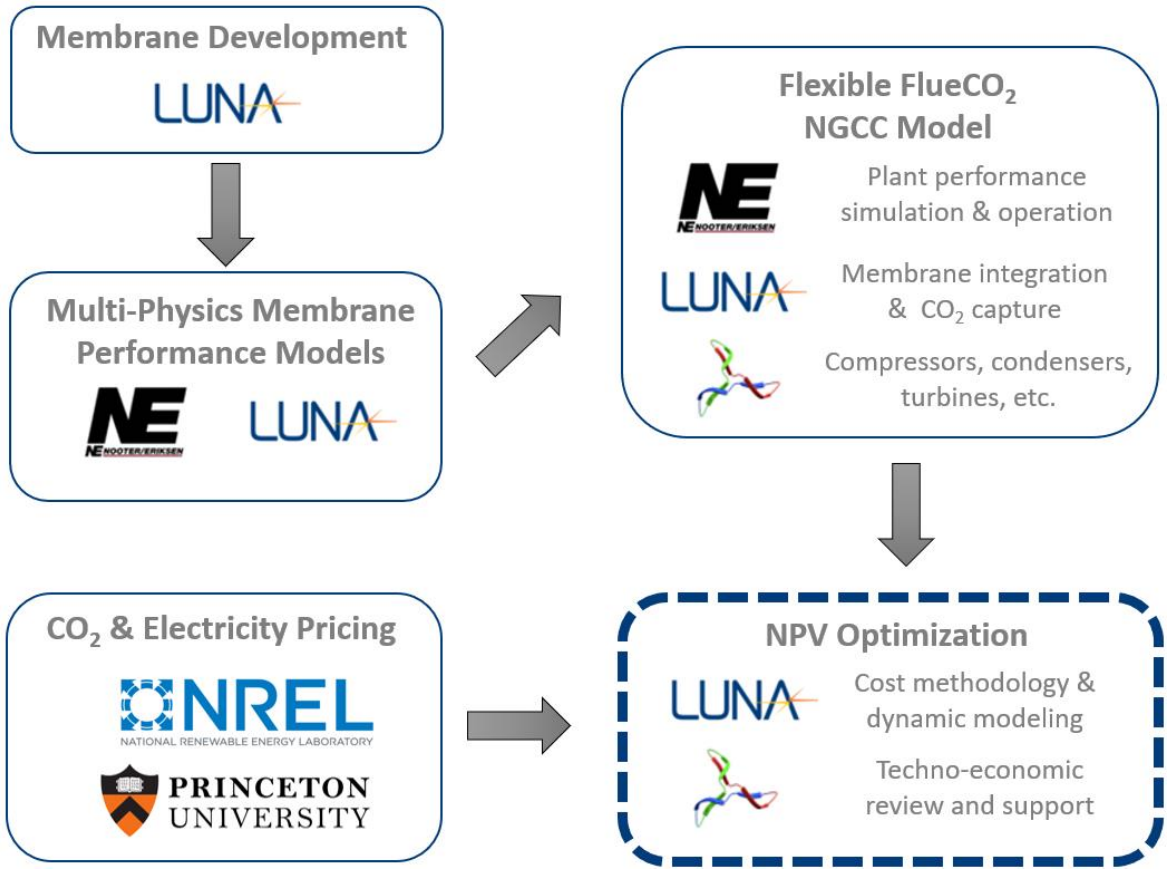
Shaun Hennessey
Nathan Ross
Greg Bommarito

- Plant design & operation guidance
- Plant performance simulation (Thermoflex)
- Lead multi-physics modeling (ANSYS)

Trimeric Corporation: process engineering firm with CO_2 capture expertise

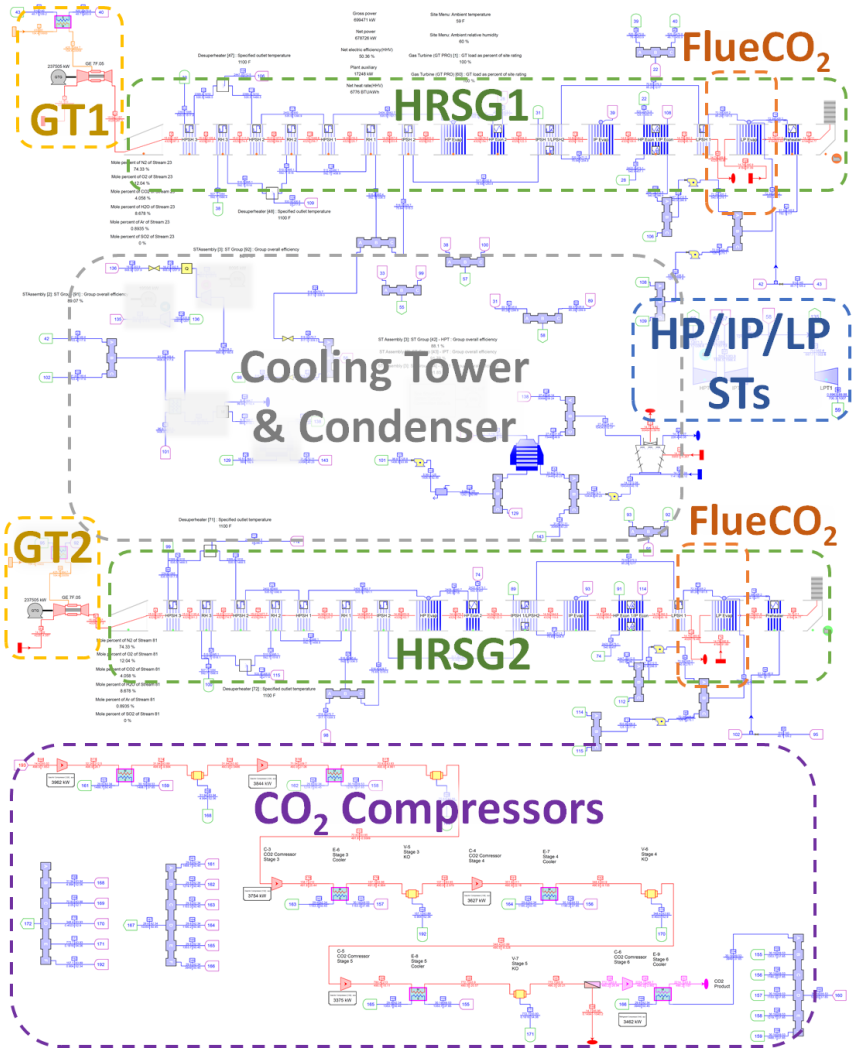
Andrew Sexton
Katherine Dombrowski
Anne Ryan

- Techno-economic analysis & review
- Compression & condensation simulation
- Equipment & design guidance



Design and Costing Methodology

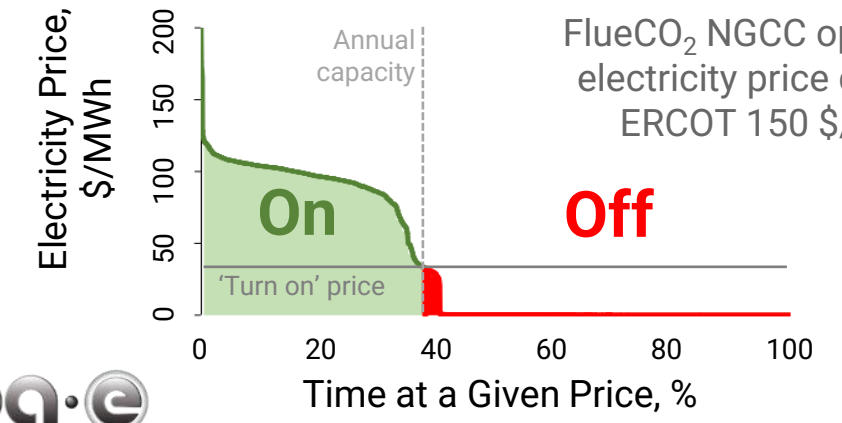
- Strict adherence to National Energy Technology Laboratory (NETL) methodologies
  - FlueCO_2 NGCC design derived from control plant (B31A)
- Interactive spreadsheet calculator available upon request
  - 30-yr NPV, LCOE, breakevens, BEC→TASC, OpEx, etc.
- Dynamic cost modeling tool for analyzing scenarios
  - Optimize plant design and operation
  - Automated data visualization tools



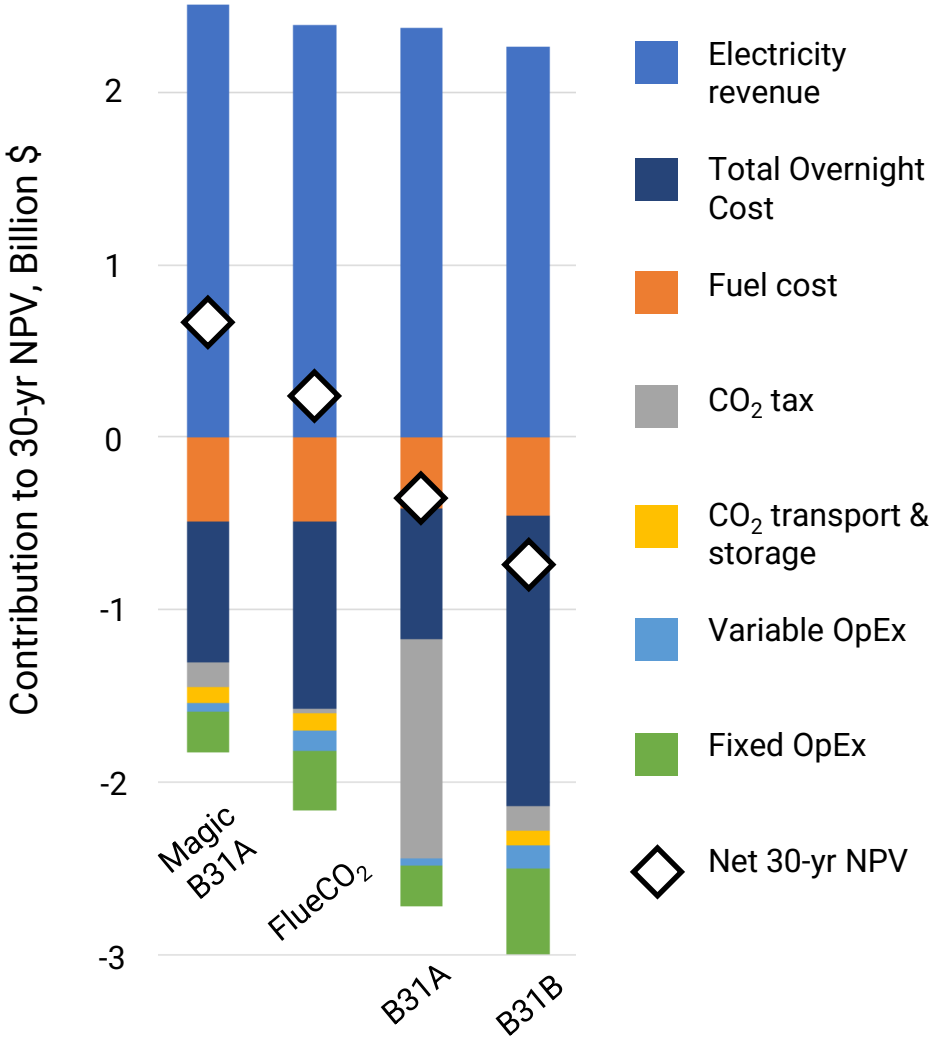
Thermoflex model of FlueCO_2 NGCC

Low Capital Costs, High Efficiency, Fast Response

- Minimal addition to total NGCC plant capital costs
  - Avoid compounding effects of taxes, financing, & insurance
- FlueCO_2 capture only causes 7% loss in net MWe output
  - ↑ Efficiency → ↓ 'turn on' MWe price → ↑ annual capacity
- FlueCO_2 NGCC responds ~as fast as B31A NGCC
  - Effectively capture the profitable electricity market opportunity



FlueCO_2 NGCC operation within electricity price distribution for ERCOT 150 $/tonne CO_2 tax



Lifetime contributions to 30-yr NPV for ERCOT $150

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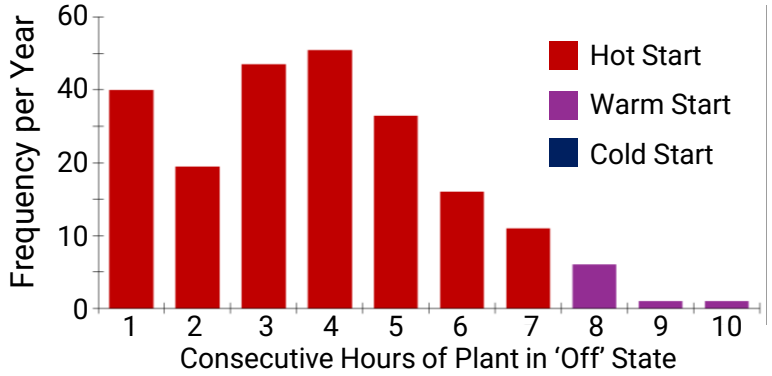
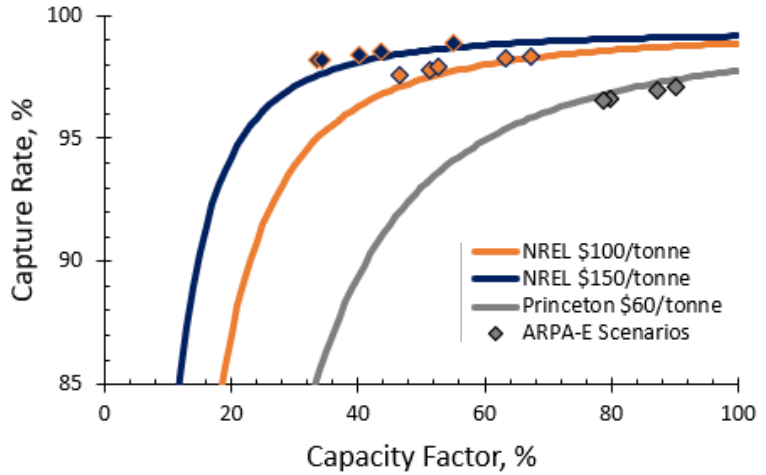
Optimization of Plant Design & Operation

- NGCC fast-start capabilities caused < +/-$40M on 30-yr NPVs
- Optimize operational forecasting caused < +$50M on 30-yr NPVs
- Robust FlueCO_2 NGCC design and operational parameters
  - Minimal customization required for a given scenario
  - Maintain competitiveness despite future market uncertainties
- Cost optimization of membrane unit size yields 96 – 99% CO_2 capture rates
  - Membrane manufacturing and lifetime costs are main uncertainty
  - Scale up and demonstrate membranes as fast as possible



Categorization of hot, warm, and cold starts for FlueCO_2 NGCC in Princeton BaseCaseTax scenario



Economically optimal CO_2 capture rates based on spreadsheet (lines) and dynamic (points) modeling

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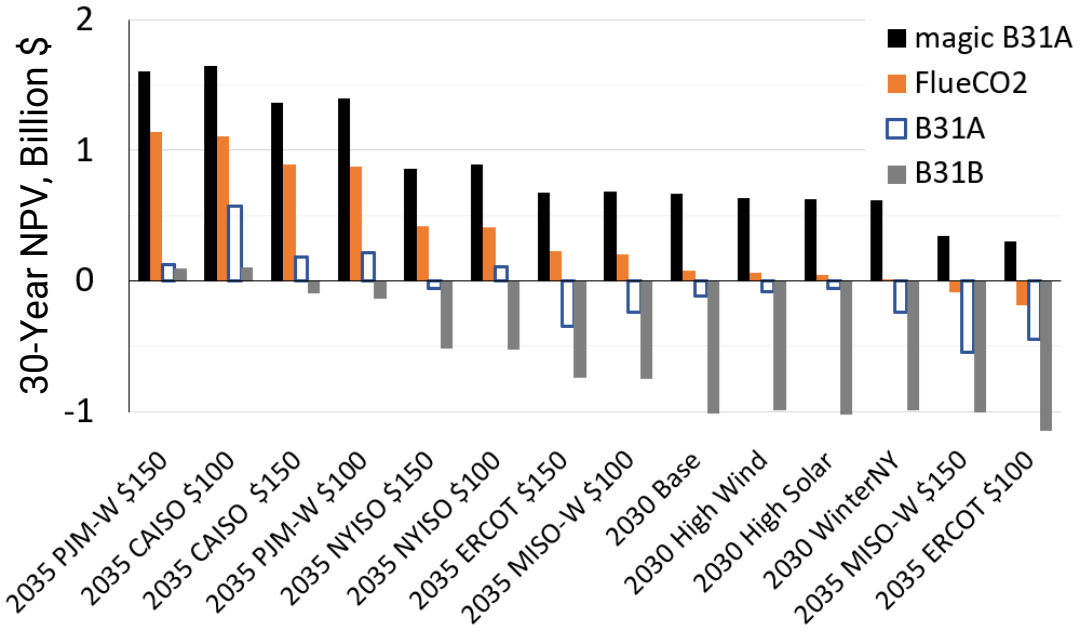
NPV-Optimized Performance

- The electricity price and emissions tax scenarios all effectively induce CO_2 capture
  - $FlueCO_2$ w/ capture outcompetes B31A w/out capture
- $FlueCO_2$ NGCC operates profitably in most scenarios
  - CO_2 is captured during >99% of operation time
- $FlueCO_2$ NPV typically ~$1B greater than B31B
  - B31B response time assumed as fast as B31A



Summary of 30-yr NPV performance results across all ARPA-E FLECCS price & tax structures

Phase II/IIS SBIR Planning

Team:

- FlueCO_2 Innovation: Luna
- Process engineering: Trimeric
- Manufacturing: in progress
- Supplier/Integrator: Nooter/Eriksen
- Purchasing, Equipment, & Construction: in progress
- Investor: in progress

Programmatic Objectives:

1. Advance plant design & costing
   - Modern, Micro, & Retrofit
   - Membrane targeting
2. Scale up membranes
   - Materials & manufacturing
   - 0.2 tonne/day demonstration
3. Commercialization
   - IP protection & dissemination
   - Partnerships & investment

FlueCO$_2$ Summary

- High Capture Rate
- High Market Size
- Robust Plant Design
- Enables practical CO_2 emission taxes
- Membranes: TRL 4/5

FlueCO$_2$ and state-of-the-art attributes for FLECCS scenarios

#	SPECIFICATION	VALUE	CONTEXT
1:	Levelized Cost of Electricity	42 – 78 $/MWe	B31A = 31 – 62 $/MWe; B31B = 60 – 113 $/MWe
2:	Breakeven Sales Price (credit)	36 – 71 $/tonne CO_2	B31B = 89 – 175 $/tonne CO_2
3:	Breakeven Emission Penalty (tax)	53 – 106 $/tonne CO_2	B31B = 114 – 226 $/tonne CO_2
4:	CO_2 Capture Rate	96 – 99%	B31B = 90%
5:	Energy Cost vs B31A	7%	B31B = 11% vs B31A
6:	Total Overnight Cost	1,586 $/kW	B31A = 990 $/kW; B31B = 2,505 $/kW
7:	370 MW HRSG Footprint Length	1.4 m	Based on multiphysics modeling for N/E HRSG
8:	Carbon Capture PEC	$280,000 per tonne/hr CO_2	Purchased Equipment Costs governed by membrane and CO_2 compressor costs